2. Assumed Design Scenarios

This chapter begins by describing an assumed communication scenario for human and robotic exploration of Mars. It is followed by a scenario relating to the CEV that will carry humans to and from Mars. These two scenarios capture the key aspects of communication needs for Mars mission support.

2.1 Scenarios for Mars Exploration

The Mars exploration communication scenario has been derived from a strawman set of requirements for human and robotic missions in the 2020 to 2030 timeframe found in references 2–1, and 2–2. Figure 2–1 show the span of data rates required for several kinds of applications that make up the scenario (ref. 2–3).

A speech channel, for example, fits within 2 kbps with compression but takes up to 80 kbps in telecom pulse code modulation (PCM) format. Synthetic aperture radar might output from as little as a few hundred kbps up to three orders of magnitude more. Similarly, a multispectral imager may output 100 kbps, but a hyperspectral imager will output four orders of magnitude more. Per-channel values for each type of application used in this report are (1) 10 kbps for speech; (2) 100 kbps for helmet-camera imaging; (3) 20 Mbps for HDTV; (4) 100 Mbps for radar; and (5) 150 Mbps for hyperspectral imaging.[3] The data rate for engineering telemetry is 20 kbps from most sources (astronauts, transports, and robotic spacecraft), but 100 kbps from the base.

Table 2–1 shows the basic and full forms of the communication scenario along with the per channel and total data rates. For each data type, a number of simultaneous channels has been assumed for purposes of constructing the working scenario. These communication scenarios

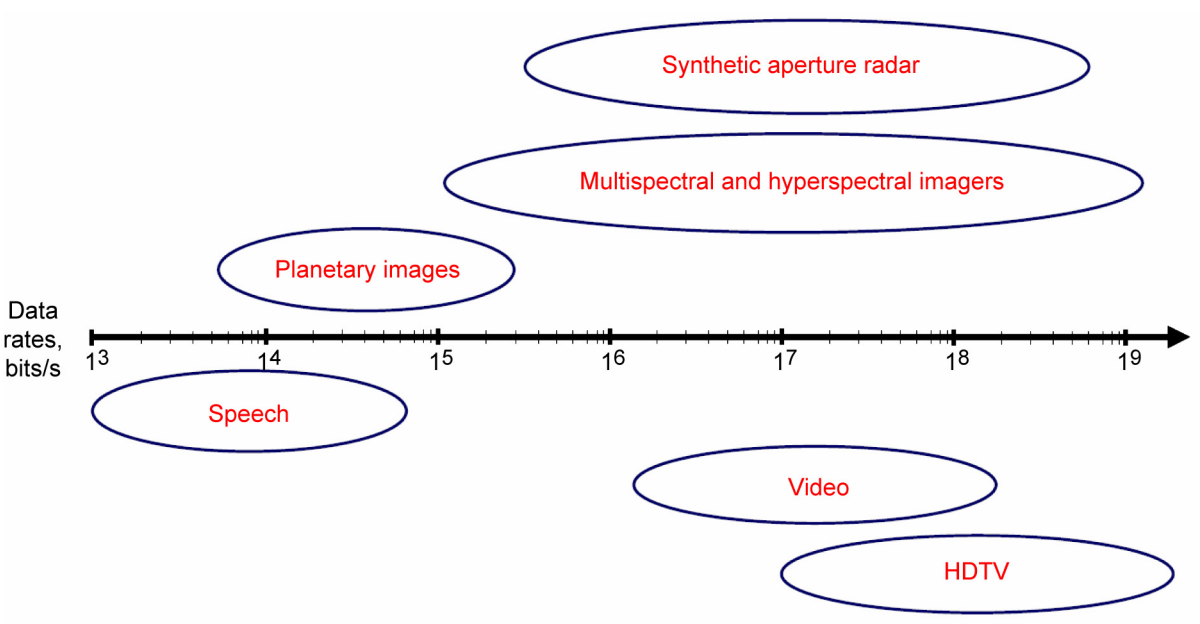

Figure 2–1.—Range of data rates for various applications.

[3]Hyperspectral sensors collect image data simultaneously in dozens or hundreds of narrow, adjacent spectral bands in contrast to multispectral sensors that produce images in a few relatively broad wavelength bands. The output from a representative hyperspectral imaging system has a transmission data rate of 150 Mbps.

TABLE 2–1.—MARS-EARTH COMMUNICATION SCENARIOS

	User	Channel Content	Latency	No. of Channels	Bit rate per channel	Total Bit Rate
Operational	Base	Speech	NRT	2	10 kbps	20 kbps
		Engineering	NRT	1	100 kbps	100 kbps
	Astronauts	Speech	NRT	4	10 kbps	40 kbps
		Helmet camera	NRT	4	100 kbps	400 kbps
		Engineering	NRT	4	20 kbps	80 kbps
	Human Transports	Video	NRT	2	1.5 Mbps	3 Mbps
		Engineering	NRT	2	20 kbps	40 kbps
	Robotic Rovers	Video	NRT	8	1.5 Mbps	12 Mbps
		Engineering	NRT	8	20 kbps	160 kbps
	Science Orbiters	Quick Look	NRT	4	1 Mbps	4 Mbps
		Engineering	NRT	4	20 kbps	80 kpbs
High Rate	Human Transports	HDTV (medical, PIO)	NRT	2	20 Mbps	40 Mbps
		Hyperspectral imaging	1 day	1	150 Mbps	150 Mbps
	Base	HDTV	1 day	1	20 Mbps	20 Mbps
	Robotic Rovers	Surface Radar	1 day	1	100 Mbps	100 Mbps
		Hyperspectral imaging	1 day	1	150 Mbps	150 Mbps
	Science Orbiters	Orbiting Radar	1 day	2	100 Mbps	200 Mbps
		Hyperspectral imaging	1 day	2	150 Mbps	300 Mbps
Total	Design Reference Mission (DRM) and HDTV - operational					**80** Mbps
	Add robotic operations and DRM hyperspectral imaging					**480** Mbps
	Add science orbiters					**980** Mbps

assume a Mars Design Reference Mission (DRM) for human communications, possibly along with a set of four science orbiters and a set of eight robotic surface vehicles (landers, rovers, etc.). Communications links to and from the Earth are via a pair of telecom orbiters around Mars.

For the exercise of the trade space and its associated technology challenges, data rates of 100 Mbps, 500 Mbps, and 1 Gbps are assumed for the partial and full scenarios. The 100 Mbps scenario would support basic operational activities; 500 Mbps case adds data from the set of robotic operations; and setting of 1 Gbps adds data from the science orbiters. The sources for these assumptions are discussed below.

The DRM presumes six astronauts on the surface, two active in a base station and four roving away from the base station in two human transports. All astronauts have two-way audio (speech) channels on radios using omnidirectional antennas, to be monitored by a relay orbiter. For numbers of channel and bandwidth sizing, the four science orbiters are presumed to have identical communications needs, as do the eight robotic rovers.

In terms of data to be brought back to Earth, the nominal scenario categorizes the communications services into operational channels and high rate channels. Because the user set includes more than one each of astronauts, human transports, rovers, science orbiters and relay

orbiters, there are as many channels of each type as instances of the user type. For example, the scenario sums to six speech channels of 10 kbps each for six astronauts.

Human communication would be sporadic but would require near-real-time (NRT) communication with high link availability. The continuity of robotic exploration would likewise require NRT and high availability for operational data, while its science would be non-real-time and high rate (volume). The scenario includes several operational and high rate services, each specifying its own quality of service (QoS).

Channels can be further categorized into four classes: emergency, operational, Public Information Office, and high volume.

- Emergency: a real-time channel requiring continuous, low-rate communication at unpredictable times and of unpredictable duration
- Operational: high availability, NRT communication needed for day-to-day operation; near 100 percent completeness on first transmission.
- Public Information Office: high reliability, NRT high-definition television (HDTV), with low frame error rate
- High volume: non-real-time, relatively low availability and relatively high frame error rate; use as yet undetermined networking protocols to accommodate goals of delay minimization and almost error-free transmission.

At the bottom of the table the scenario is parsed into three gradations. The basic form of the scenario consists mostly of operational data from the human and robotic missions, and these channels sum to about 80 Mbps. Most of the basic data is required in NRT, as limited by the communications time between Earth and Mars. The changing distance between Earth and Mars results in a variation in the communications time from 3 to 22 minutes (one way) at minimum and maximum distances, respectively. From a monitor and control perspective with Earth in the loop, two-way light time varies from 6 to 44 minutes. If an astronaut asks a question of Mission Control when at maximum range from Earth, it will be at least 44 minutes before the astronaut can hear a reply.

An intermediate stepup in the scenario results when robotic operations and some hyperspectral imaging are introduced. The total data rate would peak at ~500 Mbps though unlikely, all these sources transmitted simultaneously.

The full scenario adds radar and hyperspectral imaging to the robotic rovers and science orbiters. These, together with the scenario 1 channels, sum to about 980 Mbps. Although the full scenario also requires NRT availability for operational communication, the radar and imaging channels are not on 24 hours a day. It is clear that the instantaneous data rate for the full scenario could be substantially less than 1 Gbps most of the time. It should also be pointed out that it is very difficult to predict data needs for the year 2030. For example, three-dimensional video transmissions may require twice the rate stated in these scenarios. In this section we have made an attempt to review various user sources and provide possible bandwidth allocations based on the assumed scenarios. It is likely that the actual scenarios will be different than the assumptions made here. The goal has been to capture the possible bandwidth requirements such that even if the scenarios change, the bandwidth allocation can still support the scenarios.

In summary, data rates of 1 Gbps, 500 Mbps, and 100 Mbps are assumed in the analysis that paves the way for identifying the technology needs for high-rate Mars-to-Earth communications.

2.2 CEV Communication Scenario

Inclusion of the CEV in the overall discussion of Mars-to-Earth communications is significant. Certainly the CEV and Mars relay communication systems will not be designed without regard for one another, and in fact one may expect the two systems to share resources on Earth. At present it is hard to imagine any rationale for the CEV using optical communications to close its links to Earth. That being the case, the use of RF in a manner compatible with the future receive array seems warranted for both platforms. (Resource sharing is investigated in ch. 7.)

The data rates required for the CEV at Mars distances have not yet been determined, but can be expected to be well less that required of a Mars relay. At least one scenario for communications for the CEV would include a large data rate (~150 Mbps) from near Earth, decreasing as the CEV approached Mars vicinity. Once in contact with a Mars communications relay, the data rates from CEV could be increased significantly by the use of the relay capability near Mars.

The communication system for Mars missions must support the CEV in transit at all intermediate distances. The current best estimate of CEV communication requirements at Ka-band is that the in-transit (State 1) vehicle must be able to return up to 1 Mbps via direct link to the DSN array at Earth. In Mars orbit (State 2) the data return capability is to be tens of Mbps, in which case the vehicle can be supported by a Mars relay.

The present goal is that the Ka-band RF components on the CEV be limited to no more than 1 m antenna diameter and 100-W RF output power. The size restriction stems from the fact that the antenna will have to be gimbaled to achieve the range of pointing angles required for the various regions of operation. In addition, larger antennas may cause visual blockage problems for the crew. The present goal is that the Ka-band RF components be limited to no more than 1 m antenna diameter and 100-W RF output power. The size restriction stems from the fact that the antenna will have to be gimbaled to achieve the range of pointing angles required for the various regions of operation. In addition, larger antennas may cause visual blockage problems for the crew.

Chapter 7 of this report has as its prime objective an examination, for a Mars relay satellite, of the technology trades among spacecraft antenna size, RF output power, and ground array network from a technology risk mitigation viewpoint. Once some designs are found that offer a stipulated performance and simultaneously minimize the level of relay satellite technology complexity, the impact on the Earth-based array network can be readily derived. As a follow-up, it is interesting to see whether these derived requirements for the array are also adequate to provide the cited level of CEV support. This analysis is reported in section 7.3.

2.3 References

2–1 SCAWG RF Sub Team: Deep Space RF Trade Study Initial Report (Draft). Feb. 2005.

2–2 SCAWG RF Sub Team: Deep Space RF Trade Study Report.” Mar. 2005.

2–3 Noreen, G. et al.: Integrated Network Architecture for Sustained Human and Robotic Exploration.” 2005 IEEE Aerospace Conference, Big Sky, Montana, Mar. 5, 2005, updated Dec. 28, 2004.